# 76

Radio Location, Radio Navigation, and GPS Systems

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## 76.1 Introduction

Radio location is concerned with the use of radio waves for position sensing and locating objects. For this purpose, the radio signals can be used in an active or passive mode. In the passive mode, the characteristics of the radio signals received by a particular object situated in the field are used to determine the location. In the active case, the signals generated by an object yield the information about its location.

There are numerous radio location methods employed, being:

- Backscattered properties of waves, for example, radio-frequency identification (RFID), or radar
- Received signal strength (RSSI)
- Time of arrival (TOA)
- Differential TOA (DTOA) by receiving additional signals
- Angle of arrival (AOA)
- Phase differences and changes in frequencies, such as the Doppler shift
- Multilateration of multiple receivers that are receiving information from the same source
- Global Positioning Systems (GPS)
- Fingerprint and trilateration signals from the cellular telephony, such as TDM A, CSM A, and TSM
- Combinations of the earlier methods

Both active or passive radio location techniques are used in real-time locating systems (RTLS) for tracking and navigation purposes. There are many commercially available RTLS based on GPS, RFID, TOA, DTOA, and other techniques. Some of these will be explained in the rest of this chapter.

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76.2 Radio Location Fundamentals

Radio location technology is used extensively in military applications, industrial and transportation systems, and general consumer applications. One of the most extensively employed technologies is radio navigation, which can be classified by its range, scope, error budget, and cost. The range classifications can be identified as short, medium, and long range, within which exact limits are rather indefinite. The scope classifications can be either self-contained or externally supported, or active (transmitting) or passive (not transmitting) modes of operations.

Utilization of electromagnetic radio waves is the common denominator in all navigation systems discussed here. Particularly in the long-range applications, understanding of their behavior in the Earth’s atmosphere is very important in the design, construction, and use of all kinds of navigation equipment—from the complex satellites and radar navigation and location systems to simple handheld devices that many consumers use in their cell phones. Therefore, fundamentals behind the electromagnetic wave propagation will be explained briefly.

When an FM radio wave is generated within the Earth’s atmosphere, the wave travels outward. The waves may be absorbed or reflected from surfaces of materials they encounter. The absorption and scattering of electromagnetic waves take place for many reasons, one of which is caused by excitation of electrons within the molecules in the propagation media. The behavior of an electromagnetic wave is dependent on its frequency and corresponding wavelength. Figure 76.1 shows the frequency spectrum of electromagnetic waves. They are classified as audible waves at the lower end of the spectrum, radio waves from 5 kHz to 300 GHz, and visible light and various other types of rays at the upper end of the spectrum.

For practical purposes, the radio wave spectrum is broken into eight bands of frequencies; these are very low frequency (VLF) <30 kHz, low frequency (LF) 30–300 kHz, medium frequency (MF) 300 kHz–3 MHz, high frequency (HF) 3–30 MHz, very high frequency (VHF) 30–300 MHz, ultrahigh frequency (UHF) 300 MHz to 3 GHz, super high frequency (SHF) 3 to 30 GHz, and extremely high frequency (EHF) 30–300 GHz.

![Electromagnetic wave frequency spectrum. Radio beacons operated in the VLF, LF, and MF ranges. GPS, Transit, and Glonass use UHF frequencies. Wavelengths <10 cm are not suitable for satellite systems, but they are used in radars.](image)

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Radio Location, Radio Navigation, and GPS Systems

The radio waves are transmitted as continuous or modulated waves. A carrier wave (CW) is modulated to convey information in three basic forms: amplitude, frequency, and pulse modulation, as shown in Figure 76.2. The amplitude modulation (AM) modifies the amplitude of the CW with a modulating signal. In frequency modulation (FM), the frequency of the CW is altered in accordance with the frequency of the modulating wave. FM is used in commercial radio broadcasts and the sound portion of the television broadcast. Pulse modulation is different from AM and FM in that there is usually no impressed modulation wave employed. In this modulation, the continuous wave is broken up into very short bursts or “pulses,” separated by periods of silence during which no wave is transmitted. This is used in satellite navigation systems, surface search radars, and long-range radio navigation aids.

When an electromagnetic wave encounters an obstruction, diffraction takes place marked by a weak reception of the signal within the “shadow” zone. Two waves acting on the same point will also result in interference. The degree of interference depends on the phase and frequency relationship. For example, two waves of the same frequency with a 180° phase difference will result in a null at that point. Also, under certain conditions, a portion of the electromagnetic energy in radio waves may reflect back toward the Earth’s surface to form the ionosphere. The ionosphere is a layer of charged particles located about 90–400 km high from the Earth’s surface; such reflected waves are called sky waves.

In the study of radio wave propagation, there are four ionosphere layers of importance, as shown in Figure 76.3. The D-layer is located about 60–90 km and is formed during daylight. The E-layer is about 110 km. It persists through the night with decreased intensity. The F₁-layer is between 175 and 200 km; it occurs only during daylight. The F₂-layer is between 250 and 400 km; its strength is greatest in the day but it combines with the F₁-layer later to form a weak F-layer after dark. The layers in the ionosphere are variable, with the pattern seeming to have diurnal, seasonal, and sunspot periods. The layers may be highly conductive or may entirely hinder transmissions, depending on the frequency of the wave, the angle of incidence, height, and intensity on various layers at the time of transmission. In general, frequencies in the MF and HF bands are most suitable for ionosphere reflections during both day and night.
The four layers of the ionosphere and its effect on radio propagation. The four layers are produced by the ionization of molecules of particles in the atmosphere by ultraviolet rays of the sun. The effect of ionosphere on the radio waves is shown by reflections, also termed hops. The frequency of the electromagnetic wave is important in its behavior through the ionosphere.

Because of the higher resistance of the Earth’s crust as compared to the atmosphere, the lower portions of radio waves parallel to the Earth’s surface are slowed down, causing the waves to bend toward Earth. A wave of this type is termed a ground wave. The ground waves exist because they use the Earth’s surface as a conductor. They occur at LF since LF causes more bending in conformity to Earth’s shape. The ultimate range of such ground waves depends on the absorption effects. Sometimes, in the lower atmosphere, surface ducting occurs by multiple hopping, thus extending the range of a ground wave well beyond its normal limits. It is associated with higher radio and radar frequencies. This phenomenon is common in tropical latitudes. Behavior patterns of waves transmitted at various angles are illustrated in Figure 76.3.

### 76.2.1 Accuracy of Radio Location

There are a number of random effects that influence the accuracy of radio locations: atmospheric disturbances along the transmission path, errors in transmitters and receivers, clocks, inaccuracy in electronic circuitry, multipath, reflections, fading, etc. As a result, a series of positions determined at a given time and location usually results in a cluster of points near the true position. There are two measures commonly used to describe the accuracy: the first is the circular error probable (CEP)—a circle drawn on the true position whose circumference encompasses 50% of all indicated positions, and the second technique, more common, is the root mean square (rms), where

$$\text{rms} = \sqrt{\frac{\sum_{n=1}^{N} (E_n)^2}{N}}$$  \hspace{1cm} (76.1)

where
- $E$ is the distance between actual and predicted positions
- $N$ is the number of predicted positions

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A circle, shown in Figure 76.4, with one rms value is expected to contain 68% of all the indicated positions. Another circle of radius equal to 2 rms should contain 95% of all the indicated positions, for isotropic scattering, or errors.

In electronic navigation systems, three types of accuracy are important: (1) predictable or absolute accuracy—the accuracy of a position with respect to the geographic coordinates of the Earth; (2) repeatable accuracy—the accuracy with which the user can return to a position whose coordinates have been determined at a previous time with the same navigation system; and (3) relative accuracy—the accuracy with which a user can measure position relative to that of another user of the same system at the same time.

### 76.3 Radio Navigation

In the 1930s, improved radio direction-finding techniques and better equipment led to the establishment of systems called radio beacons. These systems consisted of small radio transmitters located in fixed places to provide radio bearings that could be used in all weather conditions. Position findings by these beacons became known as radio navigation. Continued refinements in the state-of-the-art electronics technology and a better understanding of electromagnetic wave propagation led to the subsequent development of radar and longer-range radio navigation systems.

Essentially, radio beacons are single transmitters, transmitting a continuous wave at low power, usually modulated by audible Morse code characters for identification. The transmitted signal is received by an on-board receiver incorporating a radio direction finder (RDF) to be processed further.

Many radio navigation systems were developed and perfected by various countries over many decades since 1930s. Some well-known systems are Loran-C, Decca, Consol, Omega, GEE, Alphax, Lorenz-VOR, and a few others. However, most of these radio navigation systems are outdated and shut down as they are no longer commercially or militarily can be used in an economic way. Therefore, these systems will not be explained any further. However, some still find applications in a limited way such as the VOR. As the conventional radio location systems are replaced by the technologies such as the GPS or other satellite navigation systems, communication satellites, cell phones, and the like, more attention will be on these modern techniques.
76.3.1 Radar Navigation

The word is derived from radio detection and ranging. It works on the basic principle of reflection, which determines the time required for an RF pulse to travel from a reference source to a target and return as an echo. Most surface search and navigation radar high-frequency electromagnetic waves are formed by a parabolic antenna into a beam form, as shown in Figure 76.5. The receiving antenna is rotated to scan the entire surrounding area, and the bearings to the target are determined by the orientation of the antenna at the moment the echo returns. The standard radar is made up of five components: transmitter, modulator, antenna, receiver, and indicator. They operate on pulse modulation.

Radars are extremely important devices for air-control applications. Nowadays, airborne beacon radar systems are well developed in traffic alert and collision avoidance systems (TCAS). In this system, each plane constantly emits an interrogation signal, which is received by all nearby aircrafts that are equipped appropriately. The signal triggers a transponder in the target aircraft, which then transmits some information concerning three-dimensional (3D) location and identification.

There are a number of different radar-based radio navigation systems. These systems are primarily used in the avionics industry to provide information for pilots on the position of the aircraft based on the signals transmitted from the ground stations located worldwide. This information is used as the primary or the secondary navigation aid for course determination and correction, direction finding, and distance measuring.

An example of such radio location systems is the VHF Omni directional Range (VOR). In this system, a ground station transmits two signals; one is constant in all directions while the other varies the phase relative to the first. The receiver senses the phase difference between two signals, thus yielding the information on the relative position of the aircraft with respect to the ground station. This information is suitably displayed on the cockpit panel.

An application of radar is the ground penetrating radar (GPR) used for locating objects at soil subsurface, ice, and water. In GPR, microwave band pulses are generated and the reflected signals are processed to locate objects, materials, cracks, and structures. When the generated pulses encounter a buried object or a boundary, the reflected signals vary characteristics, which can be processed suitably to reveal information about the subsurface structures. Usually, image processing techniques are used for interpretation and display. The GPR finds applications in military, geologic explorations, soils and bedrocks formation studies, archeological discoveries, underground mining, oceanography, and ice structure determinations. The penetration of signals is dependent on power level and dielectric properties of the soil. It can penetrate soil up to 15–20 m.

76.3.2 Satellite Navigation Systems

The use of satellites is a highly developed technology utilized extensively throughout the world. In the past three decades, it has progressed from quasi-experimental in nature to one with routine provisions of new services for both military and civilian use. The satellite relay systems take advantage of the unique characteristics of geostationary satellite orbits (GSOs). The design of satellite systems is well understood, but the technology is still dynamic. The satellites are useful for long-distance communication services, for services across oceans or difficult terrain, and point-to-multipoint services such as television distribution.
Satellite navigation systems use electronic receivers to determine the location of an object within a few meters using time signals transmitted from the line-of-sight satellites. The receivers calculate the time as well as position (longitude, latitude, and altitude) of the object.

Today, there are two fully operational Global Navigation Satellite Systems (GNSS): GPS of United States and GLONASS of Russia. There are a number of projects run by different countries such as the Deidou and COMPAS of China, Galileo of European Union, Doris of France, QZSS of Japan, and IRNSS of India.

Frequency allocation for satellites is controlled by the International Telecommunication Union (ITU). In the United States, the Federal Communications Commission (FCC) makes the frequency allocations and assignments for nongovernment satellite usage. The FCC imposes a number of conditions regarding construction and maintenance of in-orbit satellites.

There are many satellite systems, known as ComSats, operated by different organizations and different countries mainly developed for communications and data transmissions. These include Iridium of Motorola, Globalstar of Loral Corporation, CS series of Japan, Turksat of Turkey, Aussat of Australia, Galaxy and Satcom of the United States, Anik of Canada, TDF of France, etc. Some of the communication satellite systems are suitable for navigation purposes. However, satellite systems specifically designed for navigation are limited in numbers as indicated earlier.

The first generation of the satellite system was the Navy satellite system (Navsat), which became operational in January 1964, following the successful launch of the first transit satellite into polar orbit.

The system was declared open for private and commercial use in 1967. Civil designation of the name of the system is Transit Navigation Satellite System, or simply Transit. Later, this system evolved to become the modern Navsat GPS system, which will be discussed in detail. Most of the operational principles discussed here are inherited by the GPS system.

The Transit system consists of operational satellites, plus several orbiting spares, a network of ground tracking stations, a computing center, an injection station, a naval observatory, time signals, and receiver-computer combinations. The transit satellites are in circular polar orbits about 1075 km above ground with periods of revolution of about 107 min. Because of the rotation of the Earth beneath the satellites, every position on Earth comes within range of each satellite at least twice a day, at 12 h intervals. As originally intended, if at least five satellites are operational at any given time, the average time between five opportunities would vary from about 95 min near the equator to about 35 min or less above 70° North and South.

The Transit system is based on the Doppler shift of two frequencies, 150 and 400 MHz, transmitted simultaneously by each satellite moving its orbit at a tangential velocity of about 7.5 km/s. Two frequencies are used so that the effects of the ionosphere and atmospheric refraction on the incoming satellite transmission can be compensated for by the receiver. Each frequency is modulated by a repeating data signal lasting 2 min, conveying the current satellite time and its orbital parameters and other information. Within the receiver, a single Doppler signal is created by processing the two signals transmitted by the satellite. By plotting the frequency of this signal versus time, a characteristic curve of the type shown in Figure 76.6 is obtained. Since the frequency of the transmitted signal is compressed as the satellite approaches, according to what proportion of the velocity vector is seen by the user receiver, the curve begins at time $T_1$ at a frequency several cycles higher than the transmitted frequency.

Tracking stations record Doppler observations and memory readout received during each satellite pass to relay them to a computer center. Updated orbital position and time data communications are relayed to an “injection” station from the computer center for transmission to satellite in a burst once each 12 h. Enough data are supplied in this 15 s injection message to last for 16 h of consecutive 2 min broadcasts describing the current orbital positions of the satellite.

The system accuracy depends on the accuracy of the satellite orbit computation, the effect of ionosphere refraction, the precision of the receiver speed, and heading determination. Under optimal conditions, the system is capable of producing f xes with a maximum rms error of about 2-3 m for the stationary receivers anywhere on Earth. Errors can be reduced to give accuracy within 3 cm yielding an
absolute accuracy of 20–30 cm. Also, the time signal transmitted as a “beep” at the end of each 2 min transmission cycle coincides with even minutes of Coordinated Universal Time, which can be used as a chronometer check.

76.4 Global Satellite Navigation Systems

76.4.1 GPS

Global Satellite Navigation Systems are second-generation satellites evolved primarily from the Naval GPS. They provide a continuous 3D position-finding capability (i.e., latitude, longitude, and altitude), in contrast to the periodic two-dimensional information of the Transit system. Twenty-four operational satellites, as shown in Figure 76.7, constitute the system. Each satellite orbit is circular, about 2200 km high and inclined at angles of 55° with respect to the Earth’s axis. Some of the older satellites are taken out of service to be replaced by their advanced counterparts.

The position determination using the GPS system is based on the ability of the receivers to accurately determine the distance to the GPS satellites above the user’s horizon at the time of fix. If accurate distances of two such satellites and the heights are known, then the position can be determined. In order to do this, the receiver would need to know the exact time at which the signal was broadcast and the exact time that it was received. If the propagation speeds through the atmosphere are known, the resulting range can be calculated. The measured ranges are called pseudoranges. Nowadays, normally, information is received from at least four satellites, leading to accurate calculations of the fix. The time errors plus propagation speed errors result in range errors, common to all GPS receivers. Time is the fourth parameter evaluated by the receiver if at least four satellites can be received at a given time. If a fifth satellite is received, an error matrix can be evaluated additionally.

Each GPS satellite broadcasts simultaneously on two frequencies for the determination and elimination of ionosphere and other atmospheric effects. The Navstar frequencies are at 1575.42 and 1227.6 MHz, designated as L1 and L2 in the L-band of the UHF range. Both signals are modulated by 30 s navigation messages transmitted at 50 bits/s. The first 18 s of each 30 s frame contain ephemeris data for that particular satellite, which defines the position of the satellite as a function of time. The remaining 12 s is the almanac data, which defines orbits and operational status of all satellites in the system. The GPS receivers store and use the ephemeris data to determine the pseudorange, and the almanac data to help determine
The four best satellites to use for positional data at any given time. However, the “best four” philosophy has been overtaken slowly by an all-in-view philosophy.

The L1 and L2 satellite navigation signals are also modulated by two additional binary sequences called CIA code for acquisition of coarse navigation and the other P-code for precision ranging. The L1 signal is modulated both by the C/A and P-codes, and the L2 only by the P-code. The P-code, however, is not available for civilian users. The P-code is redesignated to be a Y-code, decipherable only by high-precision receivers having access to encrypted information in the satellite message. Civilian users have access to the so-called Standard Positioning Services (SPS), while U.S. and NATO military can use Precise Positioning Service (PPS) with better accuracy.

In enhancing SPS accuracy, differential techniques may be applied, as shown in Figure 76.8, to the encrypted GPS signals. Since the reference receiver is at a known location, it can calculate the correct ranges of pseudoranges at any time. The differences in the measured and calculated pseudoranges give the correction factors. Accuracy <1 m can be obtained in the stationary and moving measurements. Recently, differential receivers became commonly available, giving higher accuracy in subcentimeter ranges. They are getting cheaper day by day and finding applications in many areas such as airplanes, common transport vehicles, cars, geologic surveying, orienteering, farming, etc.

76.4.2 Glonass

There are a number of other satellite navigation systems similar to GPS of the United States, such as Russian Glonass. The Glonass consists of 31 satellites but 24 are in continuous use orbiting in circular form 1500 km above the ground. The accuracy of the system is about 10 m rms. Glonass satellites transmit details of their own position and a time reference. The carrier frequencies are in L-band, around 1250 MHz (L2) and 1600 MHz (L1). Only the L1 frequency carries the Civil C/A code.
FIGURE 76.8 Differential GPS operation. Satellite and target positions are sensed by ground-based receivers or mobile receivers with exact known positions. Errors of the target position due to signals received from the satellites are corrected using the information from the fixed receivers. Using this method, very high accuracy within a few centimeter ranges can be obtained.

The radio-frequency carriers used by Glonass are channelized within bands 1240–1260 MHz and 1597–1617 MHz, the channel spacing being 0.4375 MHz at the lower frequencies and 0.5625 MHz at the higher frequencies. The number of channels is 24. The data message is formatted in frames of 3000 bits, with a duration of 30 s. The ephemeris data are transmitted as a set of position, velocity, and acceleration coordinates in a Cartesian Earth-centered, Earth-centered (ECEF) coordinate system. The new ephemeris data are available every half hour, valid for the following quarter hour. The data are sent at a 50 baud rate and superimposed on a pseudorandom noise (PRN) code. The low-precision code has length 511 bits as compared to 1023 bits for Navstar. Glonass accuracy is as good as that for the GPS system. Glonass and GPS have different coordinate frames and different time frames that are being coordinated together.

76.4.3 Starfix

Another interesting satellite-based system—privately funded, developed, launched, and maintained—is the Starfix positioning system. The system is designed primarily for oil surveying. The system consists of a master site, which generates satellite ephemeris data, and four satellites in geosynchronous orbits. The system is said to have a precision of 2.5 m rms.

76.5 GPS Receivers and Their Uses

GPS receivers are devices constructed from electronic circuits, display units, and an antenna. They are supported by appropriate software. The devices are tuned to the frequencies transmitted by the satellites, and use a highly stable clock for timing purposes. Currently, there are three basic types of GPS receivers designed and built to address various user communities. These are called slow sequencing, fast sequencing, and continuous tracking receivers. The least complicated and lowest cost receiver for most applications is the slow sequencing type, wherein only one measurement channel is used to receive sequential L1 C/A code from each satellite every 1.2 s, with occasional interrupts to collect ephemeris and almanac data. Once the data are received, computation is carried out within 5 s, making this system suitable for stationary or near-stationary fixes.
Fast sequencing receivers have two channels: one for making continuous pseudorange measurements and the other for collection of the ephemeris and almanac data. This type is used in medium dynamic applications such as ground vehicles.

A number of companies produce highly sophisticated GPS receivers. EURONAV GPS receivers operate on two and four channels for military applications. They provide features such as precise time, interfacing with digital flight instruments, RS-422 interface, altimeter input, self-initialization, etc.

Software implementation satellite management functions, having different features, are offered by many manufacturers. In the case of DoD NAVSTAR GPS receivers, for example, three functional requirements are implemented: (1) database management of satellite almanac, ephemeris, and deterministic correction data; (2) computation of precise satellite position and velocity for use by navigation software; and (3) using satellite and receiver position data to periodically calculate the constellation of four satellites with optimum geometry for navigation. The DoD receivers are divided for three functions as Satellite Manager (SM), Satellite-Data-Base-Manager (SDBM) SV-Position Velocity Acceleration (SV PVA), and Select-Satellites (SS).

Differential navigation is also applied where one user set is navigating relative to another user set via a data link. In some cases, one user has been at a destination at some prior time and is navigating relative to coordinates measured at that point. The true values of this receiver's navigation fix are compared against the measured values, and the differences become the differential corrections. These corrections are transmitted to area user sets in real time, or they may be recorded for postmission use so that position fixes are free of GPS-related biases. The differential navigation and GPS systems find applications in en-route navigations for commercial and civil aviation, and military application.

GPS finds wide applications in civilian uses. Some of these applications are

- Cellular telephony for position detections
- Time setting and clock synchronizations
- Emergency services and disaster relief
- Person, wildlife, animal tracking
- Vehicle detection, tracking and navigation systems
- Geotagging, cartographies, and map making
- Navigation of ships especially in shallow waters
- Aircraft position tracking
- Orienteering, tours, recreational activities, display of information about objects such as in museums
- Surveying, land management, tracking terrain changes, and terrain and property boundaries
- Tectonics, seismic geophysical explorations, landslides, and earthquakes
- Navigation, velocity determination, and orientation measurements
- Robotics, self-navigation, and autonomous mobile systems

All these applications are supported by software in a number of ways. For example, in some applications, the vector-based maps are used for route calculations and direction finding. In others, the GPS unit sends details of the locations based on time interval and distance traveled for tracking purposes.

Most commercial software runs on Windows, Linux, Mac OS X, or Android platforms. There is much commercially available software to support GPS-based location determination and navigation, some of which are Destinator, Navigon, NDrive, ROUTE 66, Google Earth, Google Maps, Navit, VZ Navigator, and TomTom Mobile. There is also open source software such as Navit and Waze.

### 76.6 Transponders

Transponders are transducers that respond to incoming signals by generating appropriate reply messages. Recent developments in technology have made the configuration of transponders possible using elaborate and powerful on-board signal processing. This enhanced the capacity by improving
the link budgets, by adjusting the antenna patterns, and by making the satellite resources available on a demand basis—called the “switch board in the sky concept.”

Increased interest in deep sea exploration has brought acoustic transponders to the forefront as an important navigation tool. They provide 3D position information for subsurface vehicles and devices.

Some transponders are based on radar signals that respond to radar illumination. Transponders are programmed to identify friend or foe or, in some cases, simply inform ground stations about the position of aircraft.

Transponders are used for emergency warning. The U.S. and Canadian satellites carry Sarsat transponders, and Russian satellites carry Cospas transponders. They are also used as warning devices in collision avoidance systems in aircraft and land vehicles.

### 76.7 RFID Radio Location Systems

RFID uses electromagnetic propagation to transmit information from a tag attached to an object. The tag contains nonvolatile memory to digitally store information that can be read from a distance. The system requires a transmitter and a receiver. The reader transmits an encoded signal to read the tag. The tag responds with its identification codes and with the information stored in it.

RFID tags can be active or passive or battery-assisted passive. An active tag contains an on-board battery to power the system. Passive tags use the radio energy transmitted by the reader as its energy source. A battery-assisted passive tag uses a small battery on-board to activate the system in the presence of a request from the reader. Tags may be read-only or may be read/write. In read-only tags, the information is factory set and cannot be changed. Read/write tags may be written by users.

Today’s technology allows the production of small RFID chips. Hitachi produces RFID chips as small as 0.05 mm × 0.05 mm. These small-sized chips are capable of typically storing 38-digit numbers using 128 bit read-only memory (ROM). They can store information up to 2 kB of data.

RFID systems are used in

- Asset management
- Inventory systems
- Product tracking
- Transportation and logistics
- Passports
- Prevention of counterfeits such as chips in casinos
- Hospitals and healthcare
- Art theft devices such as wallets, luggage, bags, keys, etc.
- Pharmaceutical industry
- Food industry and food safety
- Livestock or wildlife identification
- Libraries, books, CDs
- Telemetry
- Electronic toll collections
- Human or animal implantations
- Personal safety and alarm systems
- Tracking personal or commercial properties, etc.

A typical application of RFID is in healthcare. They are used in multiple ways, from keeping historical information about patients and collecting the status of vital life signs to equipment tracking in hospitals, clinics, and medical centers. For example, the locations of beds, wheelchairs, surgical and other medical equipment can be realized and tracked. Active RFID tags together with other sensors are used to detect any movement of equipment as well as any tampering and environmental conditions where they are kept.
**Bibliography**


**Partial List of Manufacturers/Suppliers**

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